Renewable and Sustainable Energy Reviews 20 (2013) 201–218

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Possibility of electricity generation using PV solar plants in Serbia

Tomislav Pavlović [a,*], Dragana Milosavljević [a], Ivana Radonjić [a], Lana Pantić [a], Aleksandar Radivojević [b], Mila Pavlović [c]

[a] University of Niš, Faculty of sciences and mathematics, Department of Physics, Višegradska 33, Niš 18 000, Serbia
[b] University of Niš, Faculty of sciences and mathematics, Department of Geography, Višegradska 33, Niš 18 000, Serbia
[c] University of Belgrade, Faculty of Geography, Studentski trg 3/3, Belgrade 11 000, Serbia

A R T I C L E   I N F O

Article history:
Received 29 July 2011
Received in revised form
24 November 2012
Accepted 26 November 2012
Available online 3 January 2013

Keywords:
Solar energy
Solar cells
Fixed PV solar plants
Tracking PV solar plants
Climate conditions in Serbia
Legislative in Serbia

A B S T R A C T

The paper focuses on the possibilities of generating electrical energy by means of PV solar plants of 1 MW in Serbia. Further on basic physical characteristics of solar cells made of monocryistalline silicon, CdTe and CIS solar cells and a description of the fixed PV solar plants, one-axis and dual-axis tracking PV solar plants are given. The paper proceeds to tackle the legislative frame concerning renewable sources of energy and the current state of the use of PV systems in Serbia, climate conditions and energy potential of the renewable sources in Serbia. Apart from PVGIS solar map of Serbia real meteorological data for 17 towns in Serbia are given. Based on PVGIS program, geographycal position and the results of PVGIS calculation of the yearly average values of the optimal panel inclination, solar irradiation on the horizontal, vertical and optimally inclined plane, ratio of diffuse to global solar irradiation and linke turbidity for some cities in Serbia are given. Total for year sum of global irradiation per square meter received by the modules of the fixed PV solar plants, optimally inclined one-axis and dual-axis tracking PV solar plants of 1 MW and total for year electricity production of different types of PV solar plant of 1 MW for 23 cities in Serbia obtained by PVGIS are given. Comparison of total for year electricity production of different types of PV solar plant of 1 MW with monocrystaline silicon, CdTe and CIS solar modules, respective, for 23 cities in Serbia is given. Calculations performed by PVGIS program have shown that irrespectable of the type of PV solar plants, most electrical energy in Serbia can be generated by means of PV solar plants with CdTe solar cells. Some practical data and considerations given in this paper can be used by a customer or company keen to invest in the PV sector in Serbia.

Contents

* Corresponding author. Tel.: +38 118 225483; fax: +38 118 533014.
E-mail address: pavlovic@pmf.ni.ac.rs (T. Pavlović).

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http://dx.doi.org/10.1016/j.rser.2012.11.070

1. Introduction

Today life is organized primarily using non-renewable sources of energy–energy of the fossil fuels (coal, oil, natural gas) and nuclear energy. Enormous consumption of energy due to the alarming increase in population on the Earth leads to the critical reduction of the reserves of the fossil fuels energy sources and accompaning degradation of the environment and alarming dependance and poverty of the countries that lack this type of fuels.

Renewable energy comprises the energy of Sun, wind, water, geothermal energy, biomass, biogas, etc. The main aim of the research, development and use of renewable sources of energy in the world today is a preservation of the existing ecological balance and its reinstallment in the areas where it was disturbed. Survive and develop humankind needs to establish ecological balance and implement fast transition from the non-renewable to renewable sources of energy. From the outbreak of the energy crisis in 1973 more attention has been devoted to the use of solar cells for the production of electrical energy. Increasing number of countries is installing photovoltaic solar power plants. The main reason for this is that the use of solar energy contributes to more efficient use of the countries own potentials in generating electrical and thermal energy, reduction of ‘‘the greenhouse‘‘ emission, reduction of importing and use of the fossil fuels, development of the local industry and new job openings [1–3].

Solar photovoltaic technology earlier used mainly in the space programs or in remote locations and was marginalized and exotic. Recently it has been gaining grounds beoming a basic technology for the production and distribution of the electrical energy in urban areas with the potential to become, in terms of costs, equally competitive to the costs of energy generated and distributed by the conventional technologies.

Starting from 1990 and on industry of photovoltaic conversion of solar irradiation shows constant annual economical growth of over 20%, and from 1997 over 33% annually. In 2000 total installed capacities worldwide have surpassed 1000 MW, and in developing countries have overreached more than million households which are using eletrical energy generated by means of the photovoltaic systems. Photovoltaic power is the strongest growing of all technologies examined so far, with recent annual growth rates of around 40%.

Overgrowing number of companies and organizations is taking active part in the promotion, development and the production of photovoltaic devices and systems. Companies producing and distributing electrical energy in cooperation with the manufactureres of the solar cells, city authorities and funds are planning and realizing all major projects thus gaining necessary experiences, mobilizing the public focus and reducing the cost of electrical energy.

Most representative latest photovoltaics solar industries are leading world oil and other hi-tech companies—BP Amoco, Shell, Kyocera, Mitsubishi, Sanyo and Sharp.

Only ten years ago it was expected to utilize two most promising applications of photovoltaic systems within the sector of big several MW power plants connected to the distribution grid, or in the form of application in ten million house solar systems in the developing countries. However, current market is dominated by the urban (residential) photovoltaic systems connected with the electro-distribution grid.

Studies of the European photovoltaic industry association (EPIA) and Greenpeace organization foresee that half of 207 GW capacity in 2020 will be the systems connected to the electro-distribution grid out of which 80% will be installed in residential buildings.

Photovoltaic industry is increasingly represented in the national energy strategies of the large number of countries. Japanese Ministry of economy, commerce and industry (METI) is planning to install photovoltaic systems power of 5 GW until 2020, and until 2030 these capacities are planned to grow to 82.8 GW. It is also expected to reduce the price of the 3 kW system from 3 $/W to 1.5 $/W, in the same period.

From 1995 and on American industry of photovoltaic systems shows annual growth of 30% and the total installed capacities reach up to 350 MW.

Large multinational companies organize special branches for solar photovoltaic systems (BP, Shell, etc). On the other hand, groups that are concerned with the preservation of the environment such as the Greenpeace are actively promoting the use of photovoltaic systems with the aim of their higher market demand and reduction of prices.

Nowadays for the production of electrical energy one uses solar cells of monocrystalline, policrystalline, amorfous silicon, CdTe, CIS and solar cells made of other thin layer materials. Solar cells manufacturing prices are worldwide decreasing. In 2008 solar cells were sold at the price of 3.5 €/Wp, and in 2010 at 1.5 €/Wp [4–6].

Further on physical characteristics of solar cells and PV solar plants, perspective of photovoltaic conversion in Serbia, climate conditions in Serbia and results of electrical energy production calculations generated by the fixed, one-axis tracking and dual-axis tracking PV solar plants of 1 MW with monocrystalline silicon, CdTe and CIS solar cells in 23 cities of Serbia are given.

2. An overview of photovoltaic conversion of solar radiation

Photovoltaic conversion of the sun irradiation implies conversion of the energy of solar irradiation into the electrical energy. Photovoltaic conversion of the solar irradiation takes place in solar cells which are made of semiconducting materials, are of simple construction, do not have movable parts, do not pollute the environment and display long shelf life [7,8].

2.1. Solar cells

Solar cell is composed of p and n semiconductors where due to the absorption of sun irradiation in p–n junction pairs of electron–hole occur. Under the influence of sun irradiation solar cell in electrical circuit represents the source of direct current (DC) [7,8].

2.1.1. Solar cells of monocrystalline silicon

For the production of monocrystalline silicon solar cells a silicon is used which is next to oxigen the most represented element in the earth's crust (27.6%). Silicon belongs to the group IV of the period system of elements, is easy obtained and processed, is not toxic and does not build vironmentally harmful. In contemporary electronic industry silicon is the main semiconducting element. Electronic components made of silicon are stabile on temperatures up to 200 °C.

Semiconducting silicon is polycristalline. For it to be converted into monocristalline it is needed to melt it at 1400 °C in Czochralski process, or by method of float zone to convert it into monocrystalline. Atoms of monocrystalline silicon are connected mutually by covalent bonds into surface centered crucible. Monocrystallin silicon is black, non-transparent, very shiny, hard and weak conductor for electricity. With some additional substances monocrystalline silicon becomes a good conductor of electric current.

Solar cell composed of monocrystalline silicon has front electrode, antireflection layer, n-layer, p–n bond, p-layer and back electrode (Fig. 1). In order to obtain semiconductor of n-type silicon is doped with phosphorous, and to obtain semiconductor of p-type silicon is doped with boron. Thickness of p-layer is 300 μm, and of n-layer 0.2 μm. For antireflection layer one uses materials with refraction index of 1.5-2. These materials comprise SiO, SiO_2, TiO, TiO_2 Ta_2O_3, etc. Depending on the antireflection layer material one can manufacture monocrystalline solar cells of different colours. Metal contacts are formed by vacuum vaporing of the corresponding materials on Si plate. For this purposes one usually uses Ti/Pd/Ag coating [7,9–13].

Monocrystalline silicon solar cell is sensible to wavelengths of 0.4–1.1 μm and maximum of its sensitivity is within the range of 0.8–0.9 μm. Maximum of spectral sensitivity of the monocrystalline silicon solar cell does not coincide with the maximum of spectral distribution of sun irradiation. Commercial monocrystalline silicon solar cells have the efficiency of 15%, and laboratory ones around 24% [7,9–13].

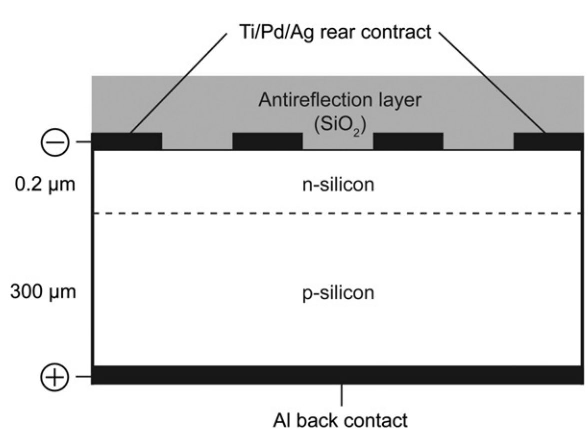

Fig. 1. Schematic cross section of solar cell made of monocrystalline silicon.

2.1.2. CdTe solar cells

Cross section for a cadmium telluride solar cell is shown in Fig. 2. A layer of cadmium sulphide is deposited from solution onto a glass sheet coated with a transparent conducting layer of thin oxide. This is followed by the deposition of the main cadmium telluride cell by variety of techniques including close-spaced sublimation, vapor transport, chemical spraying, or electroplating [7,9–13].

CdTe solar cells have been used as low cost, high efficiency, thin-film photovoltaic applications since 1970. With the forbidden zone width of ~1.5 eV and the coefficient of absorption $\sim 10^5\ cm^{-1}$, which means that a layer thickness of a few micrometers is sufficient to absorb ~90% of the incident photons, CdTe is almost an ideal material for solar cells manufacturing.

CdTe solar cell is sensitive in the wavelength of 0.3–0.95 μm and maximum of its sensitivity is in the wavelength range of 0.7–0.8 μm. Laboratory CdTe cells have the efficiency of 16%, and commercial ones around 8%. Great toxicity of tellure and its limited natural reserves diminish the prospective development and application of these cells [7,9–13].

2.1.3. CIS solar cells

The materials based on $CuInSe_2$ that are of interest for photovoltaic applications include several elements from groups I, III and VI in the periodic table. CIS is an abbreviation for general chalcopyrite films of copper indium selenide ($CuInSe_2$) [9–13].

CIS technology is a star performer in the laboratory with 19.5% efficiency demonstrated for small cells, but has proved difficult to commercialize. Unlike other thin-film technologies, which are deposited onto a glass substrate, CIS technology generally

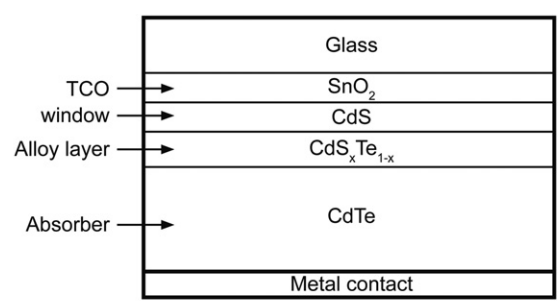

Fig. 2. Schematic cross section of solar cell made of cadmium telluride [12].

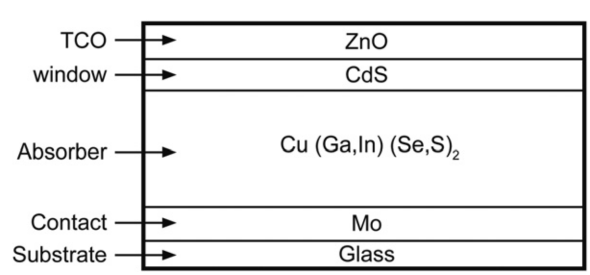

Fig. 3. Schematic cross section of solar cell made of cupper–indium–diselenide (CIS) [12].

involves deposition onto a glass substrate as shown in Fig. 3. An additional glass top-cover is then laminated to the cell/substrate combination. Present designs require a thin layer of CdS deposited from solution. Considerable effort is being directed to replacing this layer due to the issues associated with the use of cadmium, as previously noted. However, a long-term issue with CIS technology is one of available resources. All known reserves of indium would only produce enough solar cells to provide a capacity equal to all present wind generators.

$CuInSe_2$ with its optical absorption coefficient exceeding $3\times10^4\,cm^{-1}$ at wavelengths below 1000 nm, and its direct band gap being between 0.95 eV and 1.2 eV, is good material for solar cells. CIS solar cell is sensitive in the wavelength of 0.4–1.3 μm and maximum of its sensitivity is within the wavelength range of 0.7–0.8 μm.

Commercial CIS solar cells have the efficiency of 8% efficiency. However, manufacturing costs of CIS solar cells at present are high when compared to silicon solar cells but continuing work is leading to more cost-effective production processes [9–13].

Comparison of monocrystalline silicon, CdTe and CIS solar cells with their advantages and disadvantages is shown in Table 1 [11].

Prices of solar cells since 2008 to 2012 year are given in Table 2 [14].

2.2. PV solar plants

PV solar plant denotes a plant using solar cells to convert solar irradiation into the electrical energy. PV solar plant consists of solar modules, inverter converting DC into AC and transformer giving the generated power into the grid net. PV solar plant is fully automatized and monitored by the applicable software. PV solar plants mostly use solar modules made of monocrystalline and polycrystalline silicon and rarely modules made of thin film materials such as amorphous silicon, CdTe and CIS (Copper–Indium–Diselenide, $CuInSe_2$). Efficiency of the monocrystalline silicon solar cells is 15%, of polycrystalline silicon is around 12%, of amorphous silicon is around 5% and CdTe and CIS is around 8%. Monocrystalline and polycrystalline silicon solar modules are more suitable for the areas with predominantly direct sun radiation, while solar modules of thin film are more suitable for the areas with predominantly diffuse sun radiation [3,13,15,16].

Inverter is a device which converts DC generated by PV solar plants of 12 V or 24 V into three phase AD of 220 V. Depending on the design inverter efficiency is up to 97%. When choosing inverter it is to bear in mind the output voltage of the solar modules array, power of the solar modules array, grid net parameters, managing type of the PV solar plant, etc. PV solar plants can use larger number of the inverters of smaller power or one or two invertors of greater power [3,8,13,15,16].

PV solar plant monitoring system comprises central measuring–control unit for the surveillance of the working regime. Monitoring system uses sensors and softwares to obtain the following data: daily, monthly and yearly production of the electricity, reduction of CO_2, detailed change of the system parameters, recording of the events after the failure, monitoring of the meteorological parameters, etc.

PV solar plants in accordance with the power distribution systems legal regulations use transformers by means of which solar energy generated by PV solar plant is given to the power grid [3,13,15,16].

Practice shows that the energy efficiency of PV solar plant annually decreases from 0.5% to 1%. Lifetime of PV modules depends on the solar cell technology used as well. For monocrystalline and polycrystalline silicon solar cells most manufacturers give a warranty of 10/90 and 25/80 which means: a 10-year warranty that the module will operate at above 90% of nominal power and up to 25 years above 80%. The practical lifetime of the silicon-made PV modules is expected to be at least 30 years [3,17].

PV solar plants represent environmentally clean source of energy. PV solar plant components (solar modules, inverters, monitoring system, conductors, etc) are manufactured by cutting edge, environmentally friendly technologies. PV solar plants operate noiseless, do not emit harmful substances and do not emit harmful electromagnet radiation into the environment. PV solar plant recycling is also environmentally friendly. For 1 kWh of PV solar plant generated electrical energy emission of 0.568 kg CO_2 into the atmosphere is reduced [3,18].

The diurnal and seasonal movement of earth affects the radiation intensity on the solar systems. Sun-trackers move the solar systems to compensate for these motions, keeping the best orientation relative to the sun. Although using sun-tracker is not essential, its use can boost the collected energy by 10–100% in different periods of time and geographical conditions. However, it is not recommended to use tracking system for small solar panels because of high energy losses in the driving systems. It is found that the power consumption by tracking device is 2–3% of the increased energy [19].

Practice showed that the yearly optimal tilt-angle of a vertical-axis tracked solar panel for maximizing the annual energy collection was almost linearly proportional to the site latitude, and the corresponding maximum annual collectible radiation on such tracked panel was about 96% of solar radiation annually collected by a dual-axis tracked panel. Compared to the traditional fixed south-facing solar panel inclined at the optimal tilt-angle, the annual collectible radiation due to the use of the vertical-axis sun-tracking was increased by 28% in the areas with abundant solar resources and increased by 16% in the areas with poor solar resources [20].

Depending on climate conditions of given location fixed PV solar plants, one-axis and dual-axis tracking PV solar plants are

Table 2
Prices of solar cells since 2008 to 2012 year.

Early 2008	Early 2009	2009	2010	2012
~3.5 €/Wp	~2.2 €/Wp	1.8–2.2 €/Wp	~1.5 €/Wp	~1 €/Wp

Table 1
Comparison between monocrystalline silicon, CdTe and CIS solar cells with their advantages and disadvantages.

Material	Thickness	Efficiency	Colour	Features
Monocrystalline silicon (c-Si) solar cells	0.3 mm	15–18%	Dark blue, black with AR coating, grey without AR coating	Lengthy production procedure, wafer sawing necessary. Best researched solar cell material—highest power/area ratio
Cadmium Telluride (CdTe) solar cell	0.008 mm+3 mm glass substrate	6–9% (module)	Dark green, Black	Poisonous raw materials, significant decrease in production costs expected in the future
Copper–indium–diselenide (CIS)solar cell	0.003 mm+3 mm glass substrate	7.5–9.5% (module)	Black	Limited Indium supply in nature. Significant decrease in production costs possible in the future.

being installed worldwide. Fixed PV solar plants are used in regions with continental climate and tracking PV solar plants are used in tropical regions [3,13,15–17].

2.2.1. Fixed PV solar plant

Fixed PV solar plant denotes plant with solar modules mounted on fixed metal supporters under optimal angle in relation to the horizontal surface and all are oriented towards south. To install fixed PV solar plant of 1 MW it is necessary to provide around 20,000 m^2.

Maintenance costs of the fixed PV solar plants are much lesser than the maintenance costs of the tracking PV solar plants. Its drawback is in that solar modules do not follow sun radiation so that on the yearly level one does not gain optimal amount of the electricity [3,13,15–17].

2.2.2. One-axis tracking PV solar plant

One-axis tracking PV solar plant denotes a plant where solar modules installed under the optimal angle are adapted towards the sun by revolving around the vertical axis during the day from the east towards the west, following the Sun's azimuth angle from sunrise to sunset. For solar modules revolving electromotors are used using electrical energy from the batteries of the power grid. For the rotor revolving monitoring a centralized software system is used. In case software system fails solar modules can be directed towards the sun manually. It is also possible to manually set the tilt of the solar modules in relation to the horizontal surface in steps from 5° from 0° to 45°. One-axis tracking PV solar plant gives the shadow effect of solar modules situated on neighbouring rotors so that for its installation it is necessary to provide around 60 000 m^2. Available literature reports the efficiency of one-axis tracking PV solar plant is 20–25% larger than the efficiency of the fixed PV solar plant.

Instalation and maintenance costs of the one-axis tracking PV solar plants are higher than the costs of the fixed PV solar plants. Drawback of one-axis tracking PV solar plant is in that year round there is no automatic adapting of the solar module tilt towards the sun [3,15,16–20].

2.2.3. Dual-axis tracking PV solar plant

Dual-axis tracking PV solar plant denotes a plant where the position of solar modules is adapted towards the sun by revolving around the vertical and horizontal axis. These PV solar plants follow the Sun's azimuth angle from sunrise to sunset but, they also adjust the tilt angle to follow the minute-by-minute and seasonal changes in the Sun's altitude angle. Solar modules are oriented towards the sun by means of the appropriate electromotors. Photo sensors mounted on the array send signals to a controller that activates the motors, causing the array angles to change as the Sun's altitude and azimuth angles change during the day. Efficiency of the dual-axis tracking PV solar plant is 25–30% bigger than the efficiency of the fixed PV solar plant.

For the installation and function of dual-axis tracking PV solar plant a substantially bigger surface is necessary than for the fixed PV solar plant.

Instalation and maintenance costs of the dual-axis tracking PV solar plants are higher than the costs of the one-axis tracking and fixed PV solar plants [3,15–20].

When designing a large PV solar plant it is very important to optimize energy yield and occupation of land. The paper [21] gives original simulation tool with the appropriate models to calculate the energy yield for different PV solar trackers with a flat PV module grid-connected system. Based on this the relationship between the yearly average gains and land occupation has been analyzed for several tracking strategies and it has been found that the energy gains associated to one north–south axis tracking referenced to static surfaces, ranges from 18% to 25%, and from 37% to 45% for the dual-axis tracker for reasonable ground cover ratios [21].

Until December 2008 Spain installed 2382 MWp, Germany 698 MWp, USA 260 MWp, Korea 100 MWp, Italy 70 MWp, Portugal 60 MWp and other countries 102 MWp PV solar plants. Worldwide more fixed than tracking PV solar plants were installed [3].

3. Perspective of photovoltaic conversion in Serbia

3.1. Legislative in Serbia

The European Energy Law will have great impact on Serbia and its renewable energy sector. The Energy Community is extending the European Union internal energy market to Southeast Europe and beyond on the ground of legally binding treaty. Thus, Serbia, as a member of the Energy Community, has been committed to implement the relevant EU regulations concerning the energy sector step-by step. Furthermore, the ability of Serbia to assume the obligations of membership is evaluated on the basis of the implementation of the EU Acquis. The energy sector has been outlined by the European Commission as one of the fields where Serbia will have to undertake additional efforts to align with the acquis in the medium term [22].

Law on Energy of the Republic of Serbia was issued on 24 July, 2004. This law regulates: aims of the energy policy and ways of its implementation, organizational and functioning patterns of the energy market, conditions for timely and qualitative supply of consumers with the energy, and conditions for safe, reliable and efficient production of energy, management of the systems of transfer, transport and distribution of energy and ensuring of their flawless functioning and development, conditions and maners of energy actitivities implementation, conditions for enabling energy efficiency and environment protection, and finally, management and monitoring of the enforcement and implementation of this law. This law rendered possible the establishment of the Agency for energetics and the Agency for energy efficiency.

Law on Energy uses the term renewable sources of energy to denote sources of energy that can be found in Nature and are renewed partially or completely, especially energy of water, wind, non-accumulated sun energy, biomass, geothermal energy, etc.

Energy policy of the Republic of Serbia encompasses measures and activities that are being taken to realize long term aims in the area of energy and especially of:

1. Safe, qualitative and reliable supply of energy and energents.
2. Balanced development of energy activities so as to provide necessary quantity of energy and energents to satisfy the needs of the energy and energents consumers.
3. To provide conditions for the improvement of the energy efficiency and implementation of energy activities and energy consumption.
4. To provide for the conditions to stimulate the use of renewable sources of energy and combined production of the electrical and thermal energy.
5. To improve and protect the environment, etc.

Energy policy is implemented through the enforcement of the Strategy of the development of energy in the Republic of Serbia, strategy implementation program and energy balance.

Production of electrical energy encompasses production in hydroelectric power plants, thermo power plants, electro power plants, electro power plants–thermal power plants and electro power plants on renewable sources of energy or waste.

Privileged producers of electrical energy are manufacturers who in their production process of electrical energy use renewable sources of energy or waste, manufacturers who produce electrical energy in electro power plants that are according to the Law on energy considered to be small scale electro power plants and manufacturers who produce simultaneously electrical and thermal energy if they meet the criteria of the energy efficiency. Preconditions on terms of gaining this special status of the privileged manufacturer of the electrical energy and criteria for the assessment of the fulfilment of these conditions were issued by the Government of the Republic of Serbia on 3 September, 2009. Congruent to this Act legal entity or the entrepreneur can attain the privileged manufacturer status if the electro power plant in the production process on a yearly basis uses at least 90% renewable sources of energy and the rest goes to fossil fuel or waste.

Act on incentive measures for the production of electrical energy by use of the renewable sources of energy and by combined production of electrical and thermal energy was issued by the Government of Serbia on 20 November, 2009. This Act closely prescribes incentive measures for the production of the electrical energy by use of the renewable sources of energy, its purchase and it defines energy objects to produce electrical energy from the renewable sources. It also determines the content of the agreement on the purchase of the electrical energy under incentive measures, etc.

The right to the incentive measures defined by this Act for the electrical energy produced in plants which use solar energy is limited to the total installed power of (in these plants) up to 5 MW. According to this Act 1 kWh of the electrical energy produced by solar power plant in the interval of 12 years upon agreement signing is to be paid to the manufacturer at the price of 23 eurocents. Connecting of the solar power plants or small scale plants installed on private houses to the grid is regulated by the legislative of the EPS of the Republic of Serbia. Law on Energy issued on 1st August, 2011 clearly defines Incentive measures for the use of the renewable sources in power generation and subsidized power producers which is stated in the Official Gazette of the Republic of Serbia, no. 27/2011.

Republic of Serbia has in 2006 ratified the agreement on the foundation of energy community between EU and Albania, Bulgaria, Bosnia and Herzegovina, Croatia, Former Yugoslov Republic of Macedonia, Montenegro, Romania and Interim Mission of United Nations on Kosova.

In September 2008 European Parliament has adopted a set of regulations on the climate changes that aims at ensuring reduction of greenhouse effect gas emission of 20%, improvement of energy efficiency of 20% and participation of the renewable sources of energy of 20% in total energy consumption in EU- until 2020 as compared to 1990. Republic of Serbia has accepted the Instructions of the EU on the renewable sources of energy and is putting all efforts to implement it.

Republic of Serbia has on 26 January, 2009 become a member and the founder of the International Agency for Renewable Energy (IRENA) [23–26].

Renewable energy policy in the Republic of Serbia is elaborated on the paper [27]. The aim of the paper [27] is to give insight into the goals, instruments and planned measures of the Serbian Government in the field of renewable energy sources (RES). The method is based on an overview and analysis of adopted laws and regulations and other official documents. The results have revealed that progress has been made in this field in recent years. Midterm targets for the proportion of energy from RES in overall energy consumption have been defined; feed-in-tariffs have been adopted; legislative and socio-economic barriers of increased exploitation of RES have been analyzed and measures and activities for their resolution have been suggested. The existing RES-related legislation, however, is imprecise and incomplete. Numerous bylaws, technical standards and guidelines are still vague. The key RES-related documents are inconsistent, they lack clarity and are insufficiently decisive when implementing specific measures of the incentives for production of RES-based energy [27].

The analysis of the renewable energy production sector in Serbia is given in the paper [28] Producing energy from renewable sources in Serbia is in its initial phase, therefore this paper points towards the basic assumptions, potentials and institutional framework for the development of this activity in Serbia. As a final conclusion the paper states that completely unused potentials for the production of energy from renewable sources, together with adequately set institutional framework, would create great possibilities for foreign investments [28].

Opportunities and challenges for a sustainable energy policy in SE Europe: SE European Energy Community Treaty is given in the paper [29]. In this paper author has tried to systematize the role of energy sector in South Eastern (SE) Europe in the context of the European energy policy process. This paper raises awareness of the environmental requirements which have been set, of renewable energy and its implementation, at the same time pointing out that the response in SE Europe has been at a low level [29].

Perspectives of sustainable development in the countries of Southeastern Europe are given in the paper [30]. Countries of SE Europe are at the very beginning of planning of their development in accordance with theoretical concept of sustainable development. Sustainable development is defined as the basic imperative and the only model of development in a longer period of time. Special attention needs to be given to the intensive monitoring of indicators of economic and ecological subsystems. The research showed, among other things, fragile relationship of values of indicators of economic and ecological subsystems, by which any change in the values of one indicator consequently leads to the changes in the final result [30].

Kyoto Protocol implementation in Serbia as precognition of sustainable energetic and economic development is given in the paper [31]. The paper gived reasons for low energy efficiency typical for the Serbian economy, which is based on the outdated and dirty technologies. The comparison of selected economic indicators and indicators of energy efficiency in both Serbia and the European Union points out the benefits of the Kyoto Protocol implementation due to the growth of competitiveness in the global market. Energy efficiency, which is actually a question of competitiveness of each economy, can finance itself through the mechanisms of the Kyoto Protocol by selling excess emissions resulting from the improved energy efficiency [31].

3.2. Photovoltaic in Serbia

Although on most of the territory of Serbia the number of sunny days is significantly higher than in many European countries (over 2000 h), high costs of solar irradiation modules and the accompanying equipment hinder more intensive use of this renewable energy source and it will depend primarily on the social incentives for the establishment and implementation of the national Renewable Energy Sources Program. According to the available data use of solar energy is currently almost negligible. Production of solar energy, based on the sun potentials in Serbia, can be considered as attractive for potential investors, but it requires significant initial investments as well as purchasing foreign equipment, which makes it much less attractive compared to production of energy from other RES. Production of RES energy is one of the most successful ways for Serbia, as well as for other countries who signed it, to comply with the Kyoto protocol

requests and achieve adequate stage of sustainable development [28].

Perspectives and assessments of solar PV power engineering in the Republic of Serbia are given in the paper [17]. The paper [17] gives a review of some key issues and prospects related to solar photovoltaic (PV) power engineering in the Republic of Serbia. Solar PV energy sector in the Republic of Serbia is poorly developed despite a very good geographical position of Serbia and recent introduction of feed-in-tariffs (FITs) by the Serbian Government. Apart from that the paper presents the results of the electricity generation calculations for the fixed and tracking PV solar plants by means of PVGIS software in 20 towns in Serbia. The paper concludes that insufficient awareness of the opportunities of solar PV produced electricity may be an obstacle which can significantly limit and delay its use in the Republic of Serbia. At the moment solar PV technology is not implemented in the Serbian RES sector and initiatives to take some firm steps in this direction are expected [17].

The possibilites of the photovoltaic electricity production of a grid-connected urban house in Serbia are given in the paper [32]. The paper gives the results of the calculation of the electricity revenue during entire life of a two-floor house in Belgrade, Serbia and investment in PV panels (currently available on Serbian market) integrated in its entire envelope. It discussed current degree of the economic viability of this solution and suggested subventions needed to support the solar electricity production either by feed-in tariffs or other financial instruments [32].

Solar collectors and other devices for thermal conversion of sun radiation are produced in Serbia. Serbia is not a manufacturer of solar cells and other equipment for the photovoltaic conversion of sun radiation [1–3].

In Serbia one uses solar irradiation mainly for the heating of water and rarely for the electricity generation. Up to now following on-grid PV solar systems are installed in Serbia: on the elementary school *Dušan Jerković* in Ruma (3 kWp, 2004.), in the Monastery *Dević*, near the town Pirot (15 kWp, 2010.), in the middle school in Varvarin (5 kWp, 2010, *Netinvest Co.*), in the electro-technical school *Rade Končar* in Belgrade (5 kWp, 2010, *Netinvest Co.*), in the high technical school *Mihajlo Pupin* in Kula (5 kWp, 2010, *Netinvest Co.*), on the Faculty of Technical Sciences in Novi Sad (8 kWp, 2011.), on the Faculty of Electrical Engineering in Niš (1.2 kW, 2011, *Alfatec Co.*), on the Faculty of Sciences and Mathematics in Niš (2 kWp, 2012, *Alfatec Co.*), on the private house in village Blace (10.44 kWp, 2012, *Netinvest Co.*), on the private company in Leskovac (30 kWp, 2012, *Alfatec Co.*), on the private company in Čačak (55 kWp, 2012, *Electrowat Co.*), in two private houses in village Merosina of 10 kWp and 20 kWp (2012, *Telephone Engineering Co.*), in Zaječar (10 kWp, 2011, *Telephone Engineering Co.*), in village Čortanovci (10 kWp, 2012, *Telephone Engineering Co.*), in Čačak (5 kWp, 2012, *Telephone Engineering Co.*), in Zemun (2.5 kWp, 2012, *Telephone Engineering Co.*). PV solar plants in Varvarin, Belgrade and Kula were installed thanks to the donations of the Government of Spain and through the Agency for the Energy Efficiency in Belgrade within the Project *Development of the installations for the promotion and use of solar energy in Serbia* [3]. Up to now more than 200 off-grid PV systems power of 50 W–4 kW are installed in Serbia. Recently, in Serbia there is an increased use of PV systems for traffic lights and other traffic signalization.

In recently published book of the Electric Power Industry of Serbia entitled *The White Book of the Electric Power Industry of Serbia* one can find legislature of the EU referring to the renewable sources of energy, use of renewable energy in Serbia legal framework and the possibilities of the use of the renewable sources of energy in Serbia. The book cites the guidelines of the EU envisaging reducing the greenhouse gas levels by 20%, to reduce energy consumption by 20% and to provide 20% of needed energy from the renewable sources of energy by 2020. Besides, the book mentions that near Čajetina a PV solar plant of 10 MWp that would generate annually 14,710 MWh will be installed thus providing 2.8% of electrical energy for that area [14]. Foundation was laid for the construction of PV solar plant in Čajetina on 27 June in 2011. Currently three PV solar plants in Serbia are under construction: in Čajetina, in Merdare near the town Kursumlija, a fixed PV solar plant of 2 MW and in the town of Leskovac a dual-axis tracking PV solar plant of 950 kWp [3,25].

3.3. PV power engineering in some Serbia's neighbours

The paper [33] analyses energy efficiency in Serbia. The analysis has been done on the basis of energy intensity indicators for Serbia and the neighboring countries, and some other countries and regions. It relates to the period of ten years and is directed to the consideration of required interventions regarding the change of the National Energy Efficiency Policy. Regardless of constant attempts to improve and increase energy efficiency and to expand utilization of renewable energy sources it seems that accomplished results are still very modest. The analysis of several energy indicators and their changes in the midterm period confirms this statement.

In this section are given solar potential and renewable energy policy of Serbia's neighbouring countries.

3.3.1. Republic of Srpska (Bosnia and Herzegovina)

Bosnia and Herzegovina can be considered as more favourable locations in Europe with solar irradiation on horizontal surface of 1240 kWh/m^2 in the north of the country, and up to 1600 kWh/m^2 in the south. The paper [34] claims that Bosnia and Herzegovina has on average 1840.9 h of sun annually, while in the south, this number reaches 2352.5 h. The theoretical potential for Bosnia and Herzegovina is estimated to be around 74.65 PWh, while the technical potential is about 1903 TWh, both of which are substantially more than the energy needs of the country [34–36].

Solar Energy sector has not developed, yet. Electricity supplies in Bosnia and Herzegovina are essentially based on coal-fired steam turbine power stations and the exploitation of hydropower. In Bosnia and Herzegovina generally, and the Republic of Srpska particularly, rare are the examples of the use of the PV systems and there are scarce papers and PV systems studies. In Bosnia and Herzegovina and the Republic of Srpska up to date not one PV solar plant has been installed. Currently, the use of grid connected PV systems in Bosnia and Herzegovina comes down to isolated cases installed in public buildings (orphanage, schools …) with demonstration and training purposes. In 2005 the PV installed capacity was estimated at $<1\%$ of total energy supply in Bosnia and Herzegovina by the Commission of the European Communities Research Directorate. Due to a relatively high cost related to the photovoltaics up to this moment the existing facilities are carried out with the support from grants and international projects [35].

One of the first PV systems in Bosnia and Herzegovina was installed and put into service as part of the project financed by the government of Spain; the system has a total power of 0.32 kW and is used as the energy source for the irrigation system in Popovo Polje, located in Canton K7 and the Republic of Srpska. One of the first PV installations in the Republic of Srpska is being fitted on the roof of an orphanage in Trebinje. The installation is also intended to be used for the training purposes for the local electrical trade. In November 2011 a fixed PV solar plant of 2 kWp with solar modules made of monocrystalline silicon was installed on the roof at the Academy of Sciences and Arts of the Republic of Srpska in Banja Luka.

In the Republic of Srpska following feed-in tariffs (FITs) are in effect:

1. 1 kWh electricity generated by PV plants power up to 50 kWp is payed 0.285 €;
2. 1 kWh electricity generated by PV plants power from 50 kWp to 500 kWp is payed 0.245 € and
3. 1 kWh electricity generated by PV plants power over 500 kWp is payed 0.205 € [35].

3.3.2. The Former Yugoslav Republic of Macedonia (FYR Macedonia)

The Former Yugoslav Republic of Macedonia (FYR Macedonia) has better sunny conditions than Serbia with as many as 280 sunny days a year [17]. Geographic position and climate in the country offer very good perspective for the utilization of solar energy. Annual average value for daily irradiation varies from 3.4 kWh/m^2 in the northern part of the country (Skopje) to 4.2 kWh/m^2 in the southern part (Bitola). Total annual solar insolation varies from 1250 kWh/m^2 in the northern part up to a maximum of 1530 kW h/m^2 in the south-western part leading to annual solar insolation of 1385 kWh/m^2. Climate characteristics—high solar irradiation intensity as well as its duration, temperature and humidity enable favorable preconditions for development of solar energy [37].

Solar energy is used at symbolic level for water heating in households. The immense solar energy potential with 2000–2400 sunny hours during the year and generation potential of around 10 GWh per year can satisfy at least 75–80% of the annual needs for space and sanitary hot water heating. Currently its usage is limited to water heating. In Macedonia there are only 7.5 m^2 solar panels on every 1000 people, or 15,000 m^2 of installed solar panels. At the end of 2006 the total collector area in operation in Macedonia was 17,118 m^2. For example, in Cyprus this area was 811,538 m^2 while in Germany it was 1160,400 m^2. Out of 500,000 households in Macedonia only 2500–3000 are using solar systems for water heating. This represents only 0.5% of the total market for solar panels.

Apart from the advantages of solar energy for a country like Macedonia, situated on the south of Europe, poor with domestic energy resources but with long-term tradition of theoretical and experimental research in the field of photovoltaic systems, practical application of these systems is still limited to few pilot-installations in telecommunication facilities and street lighting in several municipalities. The first grid-connected solar PV power plant started to work in July 2010, near its capital Skopje, with installed power of 250 kW, and an investment price of about 1 million € [17,37].

There is no particular law related to RES development or use in the FYR Macedonia. FYR Macedonia follows actively the acts brought by the European Union in the RES area and at the same time prepares the national legislation harmonized with the EU regulations. The Ministry of Economy of the FYR Macedonia is the institution responsible for the preparation of energy legislation (The Energy Law (Official Gazette, No. 65, 2007), Strategy for the usage of RES, Strategy for energy efficiency). The Energy Agency of the FYR Macedonia (EARM) supports the implementation of the Government energy policy by preparing energy strategies, developing plans and programs, with a special emphasis on the use of the renewable energy sources (RES) and energy efficiency (EE) [38].

In order to encourage investment in photovoltaic systems Energy Regulatory Commission (ERC) has recently adopted preferential tariffs for sale of electricity produced and supplied by photovoltaic systems. With these tariffs investment in photovoltaic systems will become much more cost-efficient, but their implementation requires elimination of technical, administrative and legal barriers. Energy Regulatory Commission established the following feedin tariffs for electricity produced by PV systems:

- original price 46 eurocents/kWh for the installed capacity up to 50 kW and
- 41 eurocents/kWh for the installed capacity greater than 50 kW.

In the meantime, these tariffs were changed and currently are: 30 eurocents/kWh for the installed capacity up to 50 kW and 26 eurocents/kWh for the installed capacity of 51–1000 kW [37,38].

3.3.3. Bulgaria

Solar resource theoretical potential is the solar energy on the earth surface that is expressed as the average kilowatt-hours (kWh) of thermal energy incident on a square metre of horizontal area. This is given in daily, monthly or annual averages to obtain the theoretical or total energy available. The Institute of Hydrology and Meteorology (IHM) of the Bulgarian Academy of Sciences (BAS) has sunshine hour data from 45 sites covering 30 years and actual solar radiation (SR) measurements from 5 to 6 stations. The results from the analysis of this data using a correlation relating solar irradiation to sunshine hours show that the country falls into three solar regions:

I. region—SR $<$ 1 450 kWh/m^2/year (41% of land area);
II. region—SR: 1 450–1 500 kWh/m^2/year (52% of land area) and
III. region—SR $>$ 1 500 kWh/m^2/year (7% of land area) [39].

The paper [17] cites that Bulgaria has similar sunny conditions to Serbia (more favourable in its Black Sea region), but pays 40.5 eurocents/kWh for PV systems up to 5 kW and 37.2 eurocents/kWh for PV systems $>$5 kW and $\leq$10 MW and solar PV power engineering is booming in this neighbouring country. PV system projects are financed with reduced interest loans from the Bulgarian Government, the European Bank for Reconstruction and Development (EBRD), the Bulgarian Government and the EU. In November 2008 the duration of FIT payments for PV systems was changed from 12 to 25 years. As an additional example of good RES policy, Bulgaria wind energy capacity jumped over 300 MW by the end of 2009.

3.3.4. Croatia

The geographical location of Croatia provides very good conditions for the use of solar energy. In the southern part of Croatia, where the Mediterranean climate prevails, these conditions are even more favourable than in the rest of country. The duration of mean annual insolation over the southern Croatian (Adriatic) coast is more than 2500 h while in Dubrovnik and on some islands it even exceeds 2700 h. The Croatia solar energy potential is best described by the comparison with the European average. The Croatian southern coast has about the same average solar irradiation per day (5.1 kWh/m^2/day) as southern Europe. This is about 20% more than for the Croatian northern coastal region. For the continental Croatia the average value is 3.8 kWh/m^2/day which is about 20% more than in Central Europe. Clearly, irradiated solar energy in southern Croatia is up to 75% higher than in central and northern Europe and it is only smaller than in the most southern parts of Spain, Portugal or Greece. The technical PV potential in Croatia is difficult to estimate without specific policy assumptions as it is directly proportional to the land and roof area designated for this purposes [40].

Recently, development of national legislations environment for renewable energy sources is adopted in accordance with the European framework regarding the use of renewable energy sources within the EU. Act on incentive measures for the production of electrical energy by use of the renewable sources of energy and by combined production of electrical and thermal energy was

issued by the Government of Croatia on 22 March, 2007. Act for the electrical energy produced in plants that use solar energy is limited to the total installed power of up to 1 MW. In Croatia following feed-in tariffs (FITs) are in effect:

1. 1 kWh electricity generated by PV solar plants power up to 10 kWp is payed 0.45 €;
2. 1 kWh electricity generated by PV solar plants power from 10 kWp to 30 kWp is payed 0.397 € and
3. 1 kWh electricity generated by PV solar plants power over 30 kWp is payed 0.278 €.

3.3.5. Albania

In Albania average solar radiation is 1500 kWh/m^2 per year and maximal radiation is 2200 kWh/m^2 per year [41].

Based on a survey of world solar energy resources financed by the World Energy Council 2007, Albania receives solar radiation of more than 1500 kWh/m^2/yr, within a range of 1185 kWh/m^2/yr to 1 690 kWh/m^2/yr. The average of daily solar radiation can change from a minimum of 3.2 kWh/m^2 in the northeast up to a maximum of 4.6 kWh/m^2 in the south-west. The average daily solar radiation of the whole country is near 4.1 kWh/m^2, which can be considered as a good solar energy regime. Most areas of Albania benefit more than 2200 h of sunshine per year while the average for the whole country is about 2400 h. The Western part receives more than 2500 h of sunshine per year. Fier has a record of 2850 h. The number of the solar days in Albania has an average of 240–260 days annually with a maximum of 280–300 days annually in the south-west part. The potential of solar thermal is not merely determined by irradiation characteristics but also by the availability of roof space and orientation and inclination of the roof, the collector and storage as well [41,42].

The paper [38] claims that, in general, renewable energy data for Albania are limited. Presently, there have been no regulatory incentives identified for the development of renewable energy projects. Albania lacks legislation in the field of renewable energy sources as well as energy conservation. However, the Albanian Government has indicated awareness of this situation and is preparing an Energy Law as well as an Energy Efficiency Law. Government Decree No. 424/June 2003 approves the National Energy Strategy until 2015. According to this decree, the Ministry of Industry and Energy and the National Agency for Energy are appointed to update this strategy every two years. Energy Policy Law has a special focus on promoting the energy efficiency and energy conservation, creating an Energy Efficiency Fund, energy efficiency labeling, and promoting energy audit schemes. Environmental Protection Law No. 7664/January 1993 provides environmental impact assessment and protection schemes in Albania. This Environmental Protection Law completely revises the environmental protection schemes and measures practiced in the country until recently. According to this Law the control over the sources and causes of pollution shall be exercised by the Ministry of Health and the National Environmental Agency (NEA), upon the request of any of the parties affected [38].

The PV technology is not still used in Albania and with a very high probability will not be used even in the near future, because of the high prices which are not affordable for the private sector and households. Feed in tariffs for the electricity produced by PV systems, which might support the development of the PV market do not exist so it is very unlikely that in the near future this type of technology will be broadly implemented. The development of the concentrated solar power is not mentioned at all either in the strategy or in any other government documents, but as for the PV, for the same reasons it is not going to be relevant resource in the near future [41,42].

4. Climatic conditions in Serbia

Serbia is located between 41°46′40″ and 46°11′25″ of the north latitude and 18°06′ and 23°01′ of the east longitude [43–45]. Serbia belongs to the continental climate regions which can be divided into the continental climate in the Panonic lowlands, moderate-continental climate in lower parts of the mountain region and the mountain climate on high mountains.

Relief substantially influences the climate of Serbia. Parallel to the coast of the Adriatic Sea spreads the range of the Dinars mountains of the Montenegro which prevents more intensive encroachment of the air masses from the Adriatic Sea towards the areas of Serbia. From the other side the territory of Serbia is through the Panonic lowlands widely exposed to the climate influences from the north and east. Along the valleys of Kolubara, Velika and Južna Morava the air masses float to the north-south and vice versa. The climate of Serbia is heavily influenced by air masses of certain physical characteristics. The biggest influence is exerted by the air masses formed over Siberia, Artic, Atlantic Ocean, African land and the Mediterranean. Over these areas a field of high air pressure is formed. On the territory of Serbia often cold air from the Siberia penetrates and rarely from the Artics [43–45].

4.1. Continental (Panonic) climate in Serbia

North part of Serbia comprises vast Panonic area which is wide open and exposed to the climate influences coming from the north and the east. The Panonic lowlands show continental climate which encompasses Vojvodina and its edge up to 800 m of height. Continental climate is characterised by excessively hot summers with insufficient humidity. Winters are long and harsh and autumns and springs are mild and short. Average annual air temperatures in the Panonic area are increasing from the west towards the east and from the north to the south. Sombor at the farthest west has average annual temperature of 11.1 °C, and Jaša Tomić on the east has 14.4 °C. Average annual temperature of Palić on the farthest north is 10.6 °C, and of Belgrade on the south is 11.6 °C. The hottest month in the Panonic area is July. However, the whole area of the Panonic lowlands exhibits certain differences. From the west towards the east summer temperatures increase. For example, average July temperature in Sombor (Bačka) is 21.2 °C, and in Vršac (Banat) is 23.3 °C. The highest summer temperatures can reach 35 °C and even 44.3 °C (Stari Bečej), and in deserts they rise even up to 60 °C. Winter in Panonic area is extremely cold. The lowest winter temperatures are on the east of the region in Banat and Bačka, while it is somewhat hotter on the edge of the Panonic basen. January is the coldest month with the average temperature of −1.9 °C on Palić and 0.3 °C in Smederevo. Precipitations in the area of the Panonic lowlands are insufficient and unevenly distributed over the year. Also the territorial distribution of precipitation differs. The lowest annual rate of precipitation is to be found on the whole Panonic area in Vojvodina. On average, Banat and Bačka annualy have precipitations of around 500–600 mm, and in some years this is below 400 mm. Therefore, this area is often affected by draught. Starting from the central parts of the Panonic lowlands towards the south, west and east precipitation rises. Area near Vršac has annual precipitation of 600–800 mm. Towards the south precipitation is slowly increasing so Požarevac has annual precipitation of 609 mm and Smederevo of 650 mm [43,44].

4.2. Moderate-continental (mountain) climate in Serbia

Moderate-continental climate is dominant in the mountain range of Serbia of 800–1400 m altitude. It is characterized by

moderate hot summers, autumns longer and hotter than springs and cold winters. Mountain climate prevails in the range over 1400 m of latitude. On the territory of Serbia it is most present on the mountains Šar-planina, Prokletija, Kopaonik, Stara planina, etc. This climate type is characterized by long, cold and snowy winters and short and chilly summers.

In high lime fields and the valleys of the Mountain area of Serbia climate ranges from the moderate-continental to the mountain one. Due to the temperature inversion winters are there harsher. Summers in lime fields are pleasant and in higher ones even chilly. Extremely hot weather during summer is rear and lasts short. In confined and wind proof valleys in Serbia a real *Župna* (term derived from the places names) climate prevails. These valleys are in summer and winter hotter than their surroundings. Average monthly and annual air temperatures in Mountain region of Serbia are decreasing with the higher latitude and altitude. The lowest average monthly and annual air temperatures in Serbia are on Šar Planina, Stara Planina and Kopaonik.

Mountain region of Serbia is characterized by the *Župna* variant of the moderate-continental climate. This variant of the moderate-continental climate is typical for the Aleksandrovac, Metohija and Vranje valleys. *Župna* variant occurs as a consequence of bigger protection of the afore mentioned valleys from the penetration of cold air from the north. The mountain area of Serbia is characterized by the temperature inversions. High valleys and lime fields in the Mountain region during winter are colder than their surroundings especially at night when the nearby mountains give away cold air which lakes up in the valleys and lime fields and stays there longer. Cloudiness in the Mountain region is from 55% to 60% annually. Sunshine duration in the Mountain region of Serbia is 1500–2000 h annually. Such a small span of sunshine duration is a consequence of high cloudiness, especially in winter time. Sunshine duration span is the smallest on the mountains. On Tara sunshine duration is 1700 h annually or 4.9 h a day. On Kopaonik annual sunshine duration is 1741 h or 5 h a day. Precipitation in the Mountain region is high. On average Mountain region has 1700 mm of precipitation annually [43,44].

4.3. Meteorological data of some cities in Serbia in the period from 1961 to 2010

Yearly average values of the meteorological data of some cities in Serbia in the period from 1961 to 2010 are given in Table 3 [44].

Table 3 is formed on the basis of meteorological data of the Republic Hydrometeorological Institute of Serbia for the period 1961 to 2010. Unfortunately for Požarevac, Čačak, Nova Varoš, Kosovska Mitrovica, Đakovica i Prizren there are no continuous data for the given period.

Data in Table 3 reveal that

1. yearly sunshine duration ranges from 1604.9 h (Užice) to 2084.1 h (Pirot);
2. yearly average temperature ranges from 10.17 °C (Kuršumlija) to 12.22 °C (Belgrade);
3. yearly precipitation ranges from 409.2 mm (Novi Pazar) to 783.2 mm (Valjevo);
4. yearly humidity ranges from 68.50% (Beograd) to 77.33% (Užice);
5. yearly average overcast ranges from 51.17% (Negotin) to 60.83% (Novi Pazar) and
6. average daily sunshine duration for the afore mentioned cities is 5.4 h.

4.4. Solar irradiation in Serbia

Average solar irradiation on the territory of the Republic of Serbia ranges from 1.1 kWh/m^2/day on the north to 1.7 kWh/m^2/day on the south during January, and from 5.9 kWh/m^2/day to 6.6 kWh/m^2/day during July. On a yearly basis average value of the global solar irradiation for the territory of the Republic of Serbia ranges from 1200 kWh/m^2/year in the Northwest Serbia to 1550 kWh/m^2/year in Southeast Serbia, while in the middle part it totals to around 1400 kWh/m^2/year. Due to this fact Serbia exhibits favourable conditions for the use of solar energy and its conversion into the thermal and electrical energy [23,24,46].

Table 3
Yearly average values of the meteorological data of some cities in Serbia in the period from 1961 to 2010.

Serbian cities	Sunshine duration (h)	Temperature (°C)	Precipitation (mm)	Humidity (%)	Overcast (%)
Subotica	2112.9	10.75	550.9	69.73	54.33
Sombor	2050.1	10.86	592.7	73.75	55.58
Novi Sad	2062.4	11.18	613.3	71.28	52.67
Vršac	2060.0	11.64	660.8	70.14	52.67
Beograd	2073.2	12.22	692.5	68.50	54.00
Negotin	2083.5	11.47	632.8	70.28	51.17
Požarevac	–	–	–	–	–
Valjevo	1957.9	11.15	783.2	74.38	58.42
Kragujevac	1988.6	10.99	646.3	73.36	55.50
Užice	1604.9	10.23	757.5	77.33	53.75
Zaječar	2014.1	10.70	597.3	73.25	56.67
Čačak	–	–	–	–	–
Kruševac	1777.8	11.03	636.3	76.5	54.67
Nova Varoš	–	–	–	–	–
Niš	1956.3	11.64	591.4	70.15	55.42
Kuršumlija	1776.0	10.17	639.2	76.68	52.00
Novi Pazar	1948.0	12.18	409.2	76.75	60.83
Pirot	2084.1	10.78	595.6	74.99	54.5
Leskovac	2002.0	10.49	618.0	76.75	55.58
Kosovska Mitrovica	–	–	–	–	–
Vranje	2075.8	10.97	600.5	70.9	55.42
Đakovica	–	–	–	–	–
Prizren	–	–	–	–	–

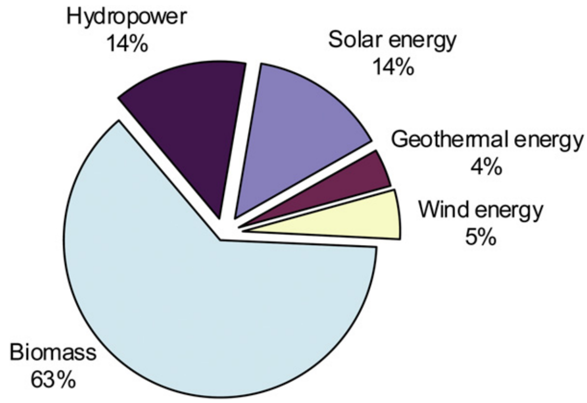

Fig. 4. Participation of some renewable sources of energy in the overall potential of Serbia [23,24].

4.5. Energy potential of the renewable sources of energy in the Republic of Serbia

Tehnically, usable energy potential of the renewable sources of energy in the Republic of Serbia is significant and estimated to over 4.3 million of tones of the equivalent oil (tn) annually—out of which around 2.7 million of tonnes of equivalent oil annually is to be used in biomass, 0.6 million of tonnes of equivalent oil annually in unused hydropotential, 0.2 million tonnes of equivalent oil annually is in the existing geothermal sources, 0.2 million of tonnes of equivalent oil annually is in energy of wind and 0.6 million of tonnes of equivalent oil annually in the use of solar irradiation. Participation of some renewable sources of energy in the overall potential of Serbia is shown in Fig. 4 [23,24].

5. PVGIS and solar maps for the territory of Serbia

Quantity of sun radiation intake on the surface of earth is influenced by numerous factors such as: geografical latitude of the given place, season of the year, part of the day, purity of the atmosphere, cloudiness, orientation and surface inclination, etc. These data are very important because of their use in calculations of the cost effectiveness of equipment using sun radiation. Very reliable data can be found in data basis PVGIS-a (Photovoltaic Geographical Information System) [3,17,47,48].

PVGIS (*Photovoltaic Geographical Information System* –PVGIS © European Communities, 2001–2008) is a part of the SOLAREC action aimed at contributing to the implementation of renewable energy in the EU. SOLAREC is an internally funded project on PV solar energy for the 7th Framework Programme PVGIS has been developed at the JRC (Joint Research Centre) of the European Commission within its Renewable Energies Unit since 2001 as a research GIS oriented tool for the performance assessment of solar PV systems in European geographical regions. From the very start of its functioning PVGIS was envisaged to be locally used, however access to the PVGIS database and estimations was drawn as open system access for professionals and the general European public as well by means of the web-based interactive applications. PVGIS provides data for the analysis of the technical, environmental and socio-economic factors of solar PV electricity generation in Europe and supports systems for EU countries solar energy decision-making.

PVGIS methodology comprises solar radiation data, PV module surface inclination and orientation and shadowing effect of the local terrain features (e.g., when the direct irradiation component is shadowed by the mountains), thus PVGIS represents immensely important PV implementation assessment tool that estimates dynamics of correlations between solar radiation, climate, atmosphere, the earth's surface and the PV technology used. Several fast web applications enable an easy estimation of the PV electricity generation potential for selected specific locations in Europe [3,17,47–50].

In order to calculate electricity generated by the fixed PV solar plants, one-axis and dual-axis tracking PV solar plants today PVGIS software packages easily found on the Intenet are used [47,50]. These programmes can produce the following data: average daily, monthly and yearly values of the solar irradiation taken on square meter of the horizontal surface or the surface tilted under certain angle in relation to the horizontal surface, change in the optimal tilting angle of the solar modules during the year, relation of global and diffused sun radiation, average daily temperature, and daily, monthly and yearly electricity generated by the fixed PV solar plants, one-axis and dual-axis tracking PV solar plants, etc. A tipical PVGIS value for the performance ratio (PV system losses) of PV solar plants with modules from monocrystalline and policrystalline silicon is taken to be 0.75 [3,17,47].

In this paper PVGIS-3 is used. The PVGIS-3 data set is based on measurements made on the ground in the period 1981–1990 which are then interpolated between points to get radiation values at any point. A new version PVGIS-CMSAF has been recently introduced which uses the new databases for the solar radiation data provided by the Climate Monitoring Satellite Application Facility (CMSAF) from the period 1998–2010. According to the possible wrong terrestrial measurements and to the fact that the amount of solar radiation has increased over Europe in the last 30 years, calculations with new PVGIS-CMSAF give higher values than with the older PVGIS-3. For the territory of Serbia PVGIS-CMSAF gives up to 5% higher values for the solar irradiation data [3,17,47].

This programme gives a map which when appears activates the programme, spots the location of the PV solar plant to be, sorts out the type of solar cells and inputs the power and type of PV solar plant (fixed, one-axis and dual-axis tracking PV solar plants) [3,17,47].

Yearly sum of total solar irradiation incident on optimally inclined south-oriented PV modules in kWh/m^2 for the territory of Serbia obtained by PVGIS is given in Fig. 5.

It is clear from Fig. 5 that average solar irradiation is not dependent on geographical latitude only. There are regional differences in global solar irradiation due to terrain features and climatic conditions.

Comparison of available annual quantities of the energy of the global sun radiation on the horizontal surface, on the territory of Germany and Serbia is given in Fig. 6. Average values of the energy of global radiation on the territory of Germany is around 1000 kWh/m^2 whereas for Serbia that value is around 1400 kWh/m^2. In Serbia sun energy evenly increases from northwest to southeast, while in germany the situation is more complex. The least values are not on the north but in the central part of the country due to increased turbidity of the atmosphere (linke turbidity) [46].

6. Results and discussion

This section gives the results obtained by the study of the solar irradiation and electricity generated by optimally inclined fixed PV solar plants, optimally inclined one-axis and dual-axis tracking PV solar plants of 1 MW with monocrystalline silicon, CdTe and CIS solar modules in 23 cities of Serbia, processed by the PVGIS software [47].

6.1. Solar irradiation in Serbia

Geographical position and the results of PVGIS calculation of the yearly average values of the optimal panel inclination, solar

irradiation on the horizontal, vertical and optimally inclined plane, ratio of diffuse to global solar irradiation and linke turbidity for some cities in Serbia are shown in Table 4.

Table 4 shows that

1. yearly average of the optimal panel inclination ranges from 32° (Negotin, Zaječar, Pirot) to 35° (Novi Pazar, Vršac, Beograd);
2. yearly average of the solar irradiation on horizontal plane ranges from 3370 Wh/m^2 (Sombor) to 4000 Wh/m^2 (Đakovica);
3. yearly average of the solar irradiation on vertical plane ranges from 2530 Wh/m^2 (Sombor) to 3010 Wh/m^2 (Đakovica);
4. yearly average of the solar irradiation on optimally inclined plane ranges from 3810 Wh/m^2 (Sombor) to 4580 Wh/m^2 (Đakovica);
5. yearly average of the ratio diffuse to global solar irradiation ranges from 0.43 (Đakovica, Prizren) to 0.51 (Pirot) and
6. yearly average of the linke turbidity ranges from 2.4 (Zaječar) to 3.7 (Subotica, Sombor).

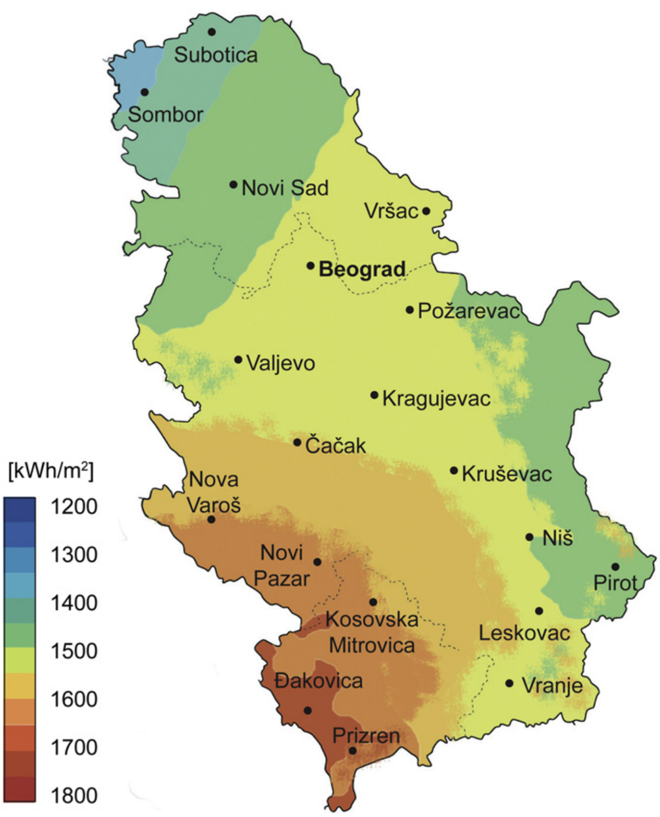

Fig. 5. Yearly sum of total solar irradiation incident on optimally inclined south-oriented PV modules in kWh/m^2 for the territory of Serbia. Adapted for Serbia from PVGIS © European Communities, 2001–2008, http://re.ec.europa.eu/pvgis/.

Total for year sum of global irradiation per square meter received by the modules of the given PV system (optimally inclined fixed PV solar plants, optimally inclined one-axis and dual-axis tracking PV solar plants) of 1 MW in some cities in Serbia obtained by PVGIS is shown in Table 5.

Table 5 shows that

1. Total for year sum of global irradiation per square meter received by the optimally inclined fixed PV solar plants of 1 MW ranges from 1390 kWh/m^2 (Sombor) to 1670 kWh/m^2 (Đakovica);
2. Total for year sum of global irradiation per square meter received by the optimally inclined one-axis tracking PV solar plants of 1 MW ranges from 1750 kWh/m^2 (Sombor) to 2170 kWh/m^2 (Đakovica);
3. Total for year sum of global irradiation per square meter received by the dual-axis tracking PV solar plants of 1 MW ranges from 1790 kWh/m^2 (Sombor) do 2230 kWh/m^2 (Đakovica);
4. In Sombor optimally inclined one-axis tracking PV solar plants of 1 MW intake 25.9% more solar irradiation compared to optimally inclined fixed PV solar plant of 1 MW, and dual-axis tracking PV solar plants of 1 MW intake 28.78% more solar irradiation compared to optimally inclined fixed PV solar plant of 1 MW and dual-axis tracking PV solar plants of 1 MW intake 2.29% more solar irradiation compared to optimally inclined one-axis tracking PV solar plants of 1 MW and
5. In Đakovica optimally inclined one-axis tracking PV solar plants of 1 MW intake 29.94% more solar irradiation than optimally inclined fixed PV solar plant of 1 MW, dual-axis tracking PV solar plants of 1 MW intake 33.54% more solar radiation than optimally inclined fixed PV solar plant of 1 MW and dual-axis tracking PV solar plants of 1 MW intake 2.77%

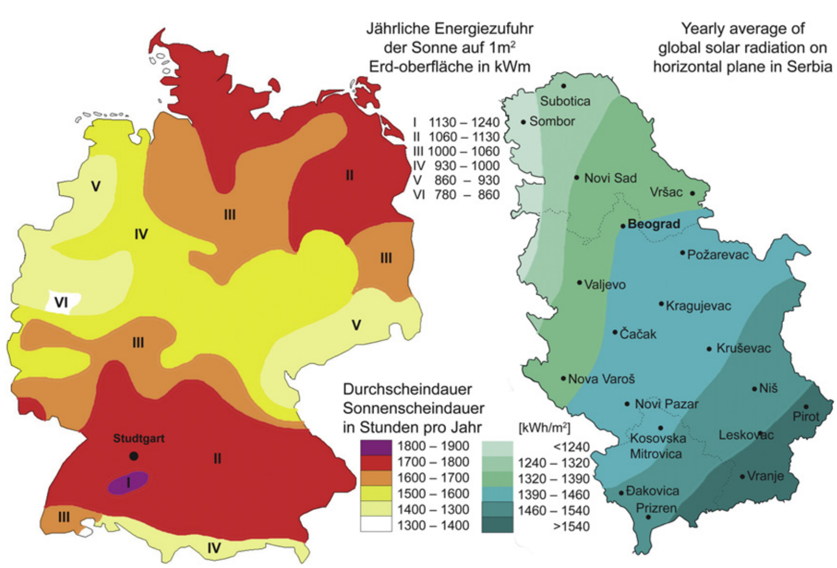

Fig. 6. Comparison of available annual quantities of the energy of the global sun radiation on the horizontal surface on the territory of Germany and Serbia [46].

Table 4
Geographycal position and the results of PVGIS calculation of the yearly average values of the optimal panel inclination, solar irradiation on the horizontal, vertical and optimally inclined plane, ratio of diffuse to global solar irradiation and linke turbidity for some cities in Serbia.

Some cities in Serbia	North latitude and east longitude	Optimal panel inclination (°)	Solar irradiation (in Wh/m²/year) Annual irradiation deficit due to shadowing (horizontal): 0–2.0%			Ratio of diffuse to global solar irradiation (−)	Linke turbidity(−)
			On horizontal plane	On vertical plane	On optimally inclined plane		
Subotica	46°4′23″ North, 19°38′36″ East	34	3430	2620	3910	0.49	3.7
Sombor	45°46′30″ North, 19°6′58″ East	34	3370	2530	3810	0.50	3.7
Novi Sad	45°14′38″ North, 19°50′28″ East	34	3550	2690	4040	0.49	3.0
Vršac	45°6′44″ North, 21°18′8″ East	35	3640	2790	4170	0.47	2.7
Beograd	44°47′36″ North, 20°27′23″ East	35	3620	2750	4130	0.47	2.8
Negotin	44°14′14″ North, 22°34′56″ East	32	3560	2600	3990	0.48	2.6
Požarevac	44°36′50″ North, 21°10′14″ East	34	3640	2750	4150	0,47	2.7
Valjevo	44°16′7″ North, 19°53′6″ East	34	3650	2780	4170	0.47	3.1
Kragujevac	44°0′31″ North, 20°55′24″ East	34	3710	2790	4210	0.47	2.7
Užice	43°54′35″ North, 19°44′12″ East	34	3700	2790	4210	0.47	3.0
Zaječar	43°53′52″ North, 22°15′29″ East	32	3640	2640	4070	0.49	2.4
Čačak	43°53′9″ North, 20°21′7″ East	34	3750	2850	4290	0.46	2.8
Kruševac	43°35′3″ North, 21°19′8″ East	33	3770	2790	4260	0.47	2.5
Nova Varoš	43°27′24″ North, 19°48′30″ East	33	3730	2750	4230	0.46	2.9
Niš	43°18′47″ North, 21°53′5″ East	33	3700	2690	4140	0.48	2.5
Kuršumlija	43°8′42″ North, 21°16′39″ East	34	3800	2840	4310	0.47	2.5
Novi Pazar	43°7′59″ North, 20°31′1″ East	35	3890	2990	4470	0.46	2.7
Pirot	43°9′40″ North, 22°35′55″ East	32	3590	2590	4000	0.51	2.5
Leskovac	43°0′2″ North, 21°56′42″ East	33	3740	2720	4190	0.48	2.5
Kosovska Mitrovica	42°52′33″ North, 20°51′46″ East	34	3890	2940	4440	0.45	2.7
Vranje	42°33′25″ North, 21°56′22″ East	33	3670	2680	4120	0.48	3.3
Đakovica	42°22′29″ North, 20°26′4″ East	34	4000	3010	4580	0.43	3.3
Prizren	42°12′29″ North, 20°43′12″ East	34	3970	2950	4520	0.43	3.4

more solar irradiation than optimally inclined one-axis tracking PV solar plants of 1 MW.

6.2. Electricity production of different types of PV solar plants of 1 MW in 23 cities in Serbia

Total for year electricity production of different types of PV solar plants of 1 MW in some cities in Serbia obtained by PVGIS is shown in Table 6.

Table 6 shows that

1. Irrespectable of the type of PV solar plants most electrical energy is generated if CdTe solar cells are used;
2. Total for year electricity production by the optimally inclined fixed PV solar plants of 1 MW with solar modules of monocrystalline silicon ranges from 1050 MWh (Sombor) to 1260 MWh (Đakovica), with CdTe solar modules it ranges from 1170 MWh (Sombor) to 1390 MWh (Đakovica) and with CIS solar modules it ranges from 1070 MWh (Sombor) to 1290 MWh (Đakovica);
3. Total for year electricity production by the optimally inclined one-axis tracking PV solar plants of 1 MW with solar modules of monocrystalline silicon ranges from 1330 MWh (Sombor) to 1650 MWh (Đakovica), with CdTe solar modules it ranges from 1460 MWh (Sombor) to 1800 MWh (Đakovica) and with CIS solar modules it ranges from 1360 MWh (Sombor) to 1680 MWh (Đakovica) and
4. Total for year electricity production by the dual-axis tracking PV solar plants of 1 MW with solar modules of monocrystalline silicon ranges from 1360 MWh (Sombor) to 1680 MWh (Đakovica), with CdTe solar modules it ranges from 1490 MWh (Sombor) to 1840 MWh (Đakovica) and with CIS solar modules it ranges from 1390 MWh (Sombor) to 1720 MWh (Đakovica).

Table 5
Total for year sum of global irradiation per square meter received by the modules of the given PV system (optimally inclined fixed PV solar plants, optimally inclined one-axis and dual-axis tracking PV solar plants) of 1 MW in some cities in Serbia obtained by PVGIS.

No.	Some cities in Serbia	Total for year sum of global irradiation per square meter received by the optimally inclined modules of the fixed pv solar plant of 1 MW (kWh/m^2/year)	Total for year sum of global irradiation per square meter received by the optimally inclined modules of the one –axis tracking pv solar plant of 1 MW (kWh/m^2/year)	Total for year sum of global irradiation per square meter received by the modules of the dual –axis tracking pv solar plant of 1 MW (kWh/m^2/year)
1.	**Subotica**	1430	1800	1840
2.	**Sombor**	1390	1750	1790
3.	**Novi Sad**	1470	1890	1930
4.	**Vršac**	1520	1980	2030
5.	**Beograd**	1510	1950	2000
6.	**Negotin**	1460	1900	1940
7.	**Požarevac**	1510	1970	2020
8.	**Valjevo**	1520	1950	2000
9.	**Kragujevac**	1540	2000	2060
10.	**Užice**	1540	1960	2010
11.	**Zaječar**	1490	1940	1990
12.	**Čačak**	1490	1940	1990
13.	**Kruševac**	1550	2040	2090
14.	**Nova Varoš**	1540	1900	1950
15.	**Niš**	1510	1970	2020
16.	**Kuršumlija**	1570	2040	2100
17.	**Novi Pazar**	1630	2110	2170
18.	**Pirot**	1460	1860	1900
19.	**Leskovac**	1530	1990	2040
20.	**Kosovska Mitrovica**	1620	2110	2170
21.	**Vranje**	1500	1900	1950
22.	**Đakovica**	1670	2170	2230
23.	**Prizren**	1650	2110	2170

Estimated losses in PV solar plants of 1 MW in some cities in Serbia obtained by PVGIS are shown in Table 7.

Comparison of total for year electricity production of different types of PV solar plants with monocrystaline silicon solar modules of 1 MW in some cities in Serbia is shown in Fig. 7.

Fig. 7 shows that

1. In Sombor by means of dual-axis tracking PV solar plant of 1 MW with solar modules of monocrystalline silicon 29.53% more electrical energy is generated compared to optimally inclined fixed PV solar plant of 1 MW with solar modules of monocrystalline silicon and 2.26% more electrical energy is generated than in case of optimally inclined one-axis tracking PV solar plants of 1 MW with solar modules of monocrystalline silicon and
2. In Đakovica by means of dual-axis tracking PV solar plant of 1 MW with solar modules of monocrystalline silicon 33.34% more electrical energy is generated compared to optimally inclined fixed PV solar plant of 1 MW with solar modules of monocrystalline silicon and 1.82% more electrical energy is generated than by means of optimally inclined one-axis tracking PV solar plants of 1 MW with solar modules of monocrystalline silicon.

Comparison of total for year electricity production of different types of PV solar plants with CdTe solar modules of 1 MW in some cities in Serbia is shown in Fig. 8.

Fig. 8 shows that

1. In Sombor by means of dual-axis tracking PV solar plant of 1 MW with CdTe solar modules 27.35% more electrical energy is generated than in case of optimally inclined fixed PV solar plant of 1 MW with CdTe solar modules and 2.06% more electrical energy in comparison to optimally inclined one-axis tracking PV solar plants of 1 MW with CdTe solar modules and
2. In Đakovica by means of dual-axis tracking PV solar plant of 1 MW with CdTe solar modules 32.38% more electrical energy is generated than by optimally inclined fixed PV solar plant of 1 MW with CdTe solar modules and 2.23% more electrical energy is generated than by optimally inclined one-axis tracking PV solar plants of 1 MW with CdTe solar modules.

Comparison of total for year electricity production of different types of PV solar plants with CIS solar modules of 1 MW in some cities in Serbia is shown in Fig. 9.

Fig. 9 shows that

1. In Sombor by means of dual-axis tracking PV solar plant of 1 MW with CIS solar modules 29.91% more electrical energy is generated than by optimally inclined fixed PV solar plant of 1 MW with CIS solar modules and 2.21% more electrical energy is generated than by optimally inclined one-axis tracking PV solar plants of 1 MW with CIS solar modules and
2. In Đakovica by means of dual-axis tracking PV solar plant of 1 MW with CIS solar modules 33.34% more electrical energy is generated than by optimally inclined fixed PV solar plant of 1 MW with CIS solar modules and 2.38% more electrical energy is generated than by optimally inclined one-axis tracking PV solar plants of 1 MW with CIS solar modules.

7. Conclusion

In the light of all afore mentioned one can conclude that nowadays worldwide PV solar plants mainly use solar cells made of monocrystalline, policrystalline and amorfous silicon, CdTe and CIS solar cells. Based on climate and other conditions fixed, one-axis, and dual-axis tracking PV solar plants are installed worldwide. Although Serbia has very favourable climate and legal

Table 6
Total for year electricity production of different types of PV solar plant of 1 MW in some cities in Serbia.

No.	Some cities in Serbia	Total for year electricity production of optimally inclined fixed pv solar plant of 1 MW (MWh)			Total for year electricity production of optimally inclined one –axis tracking pv solar plant of 1 MW (MWh)			Total for year electricity production of dual –axis tracking pv solar plant of 1 MW (MWh)		
		c-Si solar modules	CdTe solar modules	CIS solar modules	c-Si solar modules	CdTe solar modules	CIS solar modules	c-Si solar modules	CdTe solar modules	CIS solar modules
1.	Subotica	1080	1200	1100	1380	1510	1400	1400	1540	1430
2.	Sombor	1050	1170	1070	1330	1460	1360	1360	1490	1390
3.	Novi Sad	1110	1230	1130	1430	1560	1460	1460	1590	1490
4.	Vršac	1140	1260	1160	1490	1630	1520	1520	1660	1560
5.	Beograd	1130	1250	1150	1470	1610	1500	1500	1640	1540
6.	Negotin	1090	1210	1110	1420	1550	1450	1450	1580	1490
7.	Požarevac	1130	1250	1160	1480	1620	1520	1520	1660	1550
8.	Valjevo	1150	1270	1170	1480	1610	1510	1510	1650	1550
9.	Kragujevac	1150	1270	1180	1510	1650	1540	1540	1680	1580
10.	Užice	1170	1280	1190	1490	1620	1530	1530	1650	1560
11.	Zaječar	1110	1230	1130	1450	1580	1480	1480	1610	1520
12.	Čačak	1130	1300	1200	1480	1680	1570	1520	1720	1610
13.	Kruševac	1160	1280	1180	1530	1670	1560	1560	1700	1600
14.	Nova Varoš	1170	1290	1200	1440	1570	1480	1470	1600	1510
15.	Niš	1130	1250	1150	1470	1610	1510	1500	1640	1540
16.	Kuršumlija	1180	1300	1210	1540	1680	1580	1580	1710	1610
17.	Novi Pazar	1240	1360	1260	1600	1740	1640	1640	1780	1680
18.	Pirot	1090	1200	1110	1390	1510	1420	1410	1540	1450
19.	Leskovac	1140	1260	1170	1490	1630	1530	1520	1660	1560
20.	Kosovska Mitrovica	1220	1350	1250	1600	1730	1630	1630	1770	1670
21.	Vranje	1140	1250	1160	1440	1570	1480	1470	1600	1510
22.	Đakovica	1260	1390	1290	1650	1800	1680	1680	1840	1720
23.	Prizren	1240	1380	1270	1600	1750	1630	1630	1790	1670

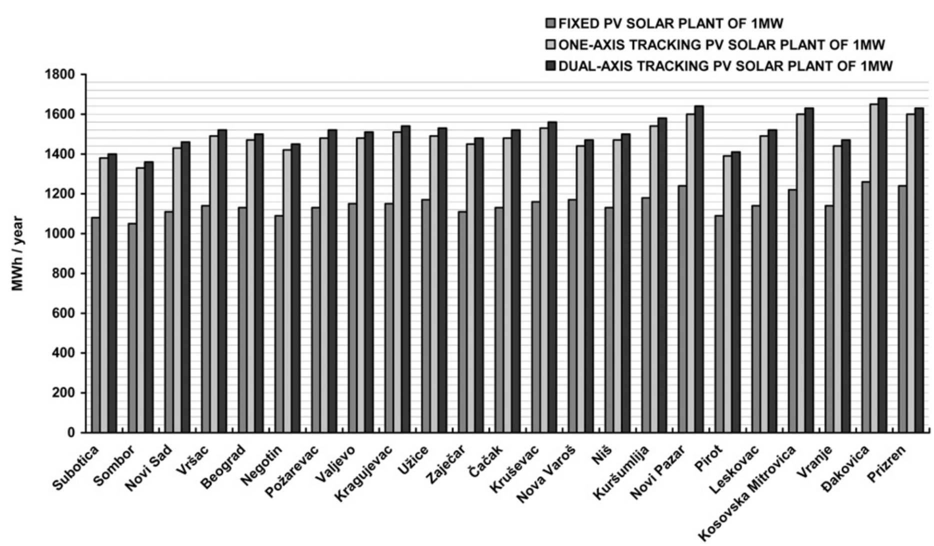

Fig. 7. Comparison of total for year electricity production of different types of PV solar plants with monocrystaline silicon solar modules of 1 MW in some cities in Serbia.

conditions for the installation and use of PV solar plants rare are the examples of the use of PV solar plants for the generation of electrical energy in private households and state objects. First on-grid PV solar plant of 3 kWp in Serbia was installed in 2004 on the roof of the elementary school *Dušan Jerković* in Ruma. Three on-grid PV solar plants of 5 kWp were installed in 2010 on high schools in Belgrade, Kula and Varvarin. Afore mentioned PV solar plants are used for demonstrational and educational purposes. Besides, up to now following on-grid PV solar systems are installed in Serbia: in the Monastery *Dević*, near the town Pirot (15 kWp, 2010), on the Faculty of Technical Sciences in Novi Sad (8 kWp, 2011.), on the Faculty of Electrical Engineering in Niš (1.2 kW, 2011), on the Faculty of Sciences and Mathematics in Niš (2 kWp, 2012), on the private house in village Blace (10.44 kWp, 2012), on the private company in Leskovac (30 kWp, 2012), on the private company in Čačak (55 kWp, 2012), in two private houses in village Merosina of 10 kWp and 20 kWp (2012), in Zaječar (10 kWp, 2011), in village Čortanovci (10 kWp, 2012), in Čačak (5 kWp, 2012), in Zemun (2.5 kWp, 2012). Currently three PV solar plants in Serbia are under construction: in Čajetina, a fixed PV solar plant of 10 MW, in Merdare near the town Kursumlija, a fixed PV solar plant of 2 MW and in the town of Leskovac a dual-

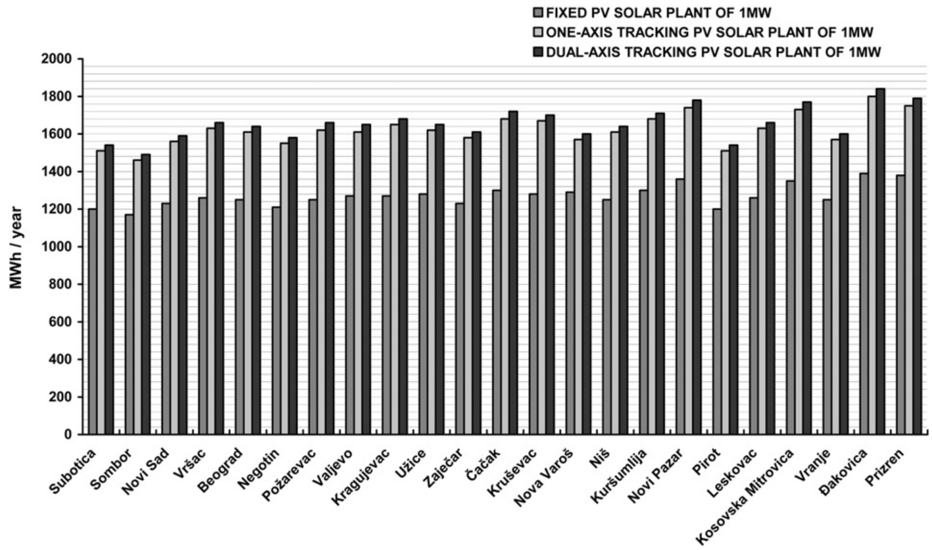

Fig. 8. Comparison of total for year electricity production of different types of PV solar plants with CdTe solar modules of 1 MW in some cities in Serbia.

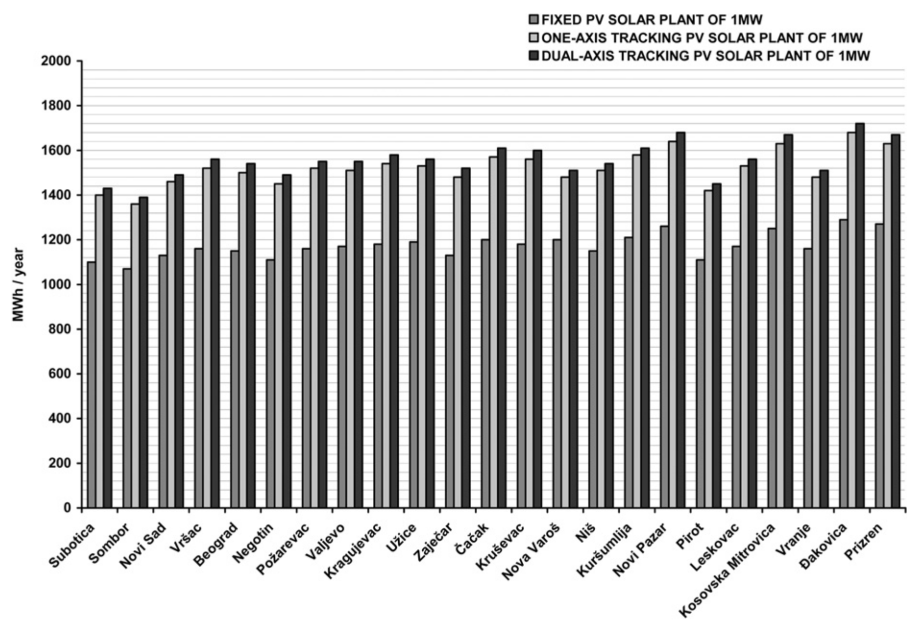

Fig. 9. Comparison of total for year electricity production of different types of PV solar plants with CIS solar modules of 1 MW in some cities in Serbia.

axis tracking PV solar plant of 950 kWp. Up to now more than 200 off-grid PV systems power of 50 W–4 kW are installed in Serbia. Recently, in Serbia there is an increased use of PV systems for traffic lights and other traffic signalization.

Application of PVGIS program in 23 towns in Serbia shows that yearly average of the optimal panel inclination ranges from 32° to 35°; total for year sum of global irradiation per square meter received by the optimally inclined fixed PV solar plants of 1 MW ranges from 1390 kWh (Sombor) to 1670 kWh (Đakovica); total for year sum of global irradiation per square meter received by the optimally inclined one-axis tracking PV solar plants of 1 MW ranges from 1750 kWh (Sombor) to 2170 kWh (Đakovica); total for year sum of global irradiation per square meter received by the dual-axis tracking PV solar plants of 1 MW ranges from 1790 kWh (Sombor) to 2230 kWh (Đakovica).

Total for year electricity production by the optimally inclined fixed PV solar plants of 1 MW with solar modules of monocrystalline silicon ranges from 1050 MWh (Sombor) to 1260 MWh (Đakovica), with CdTe solar modules ranges from 1170 MWh (Sombor) to 1390 MWh (Đakovica) and with CIS solar modules it ranges from 1070 MWh (Sombor) to 1290 MWh (Đakovica).

Total for year electricity production by the optimally inclined one-axis tracking PV solar plants of 1 MW with solar modules of monocrystalline silicon ranges from 1330 MWh (Sombor) to 1650 MWh (Đakovica), with CdTe solar modules it ranges from 1460 MWh (Sombor) to 1800 MWh (Đakovica) and with CIS solar modules it ranges from 1360 MWh (Sombor) to 1680 MWh (Đakovica).

Total for year electricity production by the dual-axis tracking PV solar plants of 1 MW with solar modules of monocrystalline silicon ranges from 1360 MWh (Sombor) to 1680 MWh (Đakovica), with CdTe solar modules it ranges from 1490 MWh (Sombor) to 1840 MWh (Đakovica) and with CIS solar modules it ranges from 1390 MWh (Sombor) to 1720 MWh (Đakovica).

Table 7
Esstimated losses in PV solar plants of 1 MW in some cities in Serbia obtained by PVGIS [34].

Some cities in Serbia	Estimated losses due to temperature (using local ambient temperature) on:			Estimated loss due to angular reflectance effects on:			Other losses (cables, inverter etc.):			Combined PV system losses on:		
	c-Si solar modules (%)	CdTe solar modules (%)	CIS solar modules (%)	c-Si solar modules (%)	CdTe solar modules (%)	CIS solar modules (%)	c-Si solar modules (%)	CdTe solar modules (%)	CIS solar modules (%)	c-Si solar modules (%)	CdTe solar modules (%)	CIS solar modules (%)
Subotica	9.0	−0.3	7.5	2.8	2.8	2.8	14	14	14	23.9	16.2	22.7
Sombor	9.1	−0.3	7.6	2.9	2.9	2.9	14	14	14	24.0	16.2	22.8
Novi Sad	9.7	0.3	8.1	2.9	2.9	2.9	14	14	14	24.5	16.7	23.2
Vršac	9.9	0.7	8.2	2.9	2.9	2.9	14	14	14	24.7	17.0	23.3
Beograd	9.9	0.6	8.2	2.9	2.9	2.8	14	14	14	24.7	16.9	23.3
Negotin	10.2	0.9	8.6	3.0	3.0	3.0	14	14	14	25.1	17.3	23.7
Požarevac	10.0	0.7	8.3	2.9	2.9	2.9	14	14	14	24.8	17.1	23.4
Valjevo	9.3	0.3	7.7	2.8	2.8	2.8	14	14	14	24.2	16.7	22.9
Kragujevac	9.8	0.7	8.2	2.9	2.9	2.9	14	14	14	24.7	17.1	23.3
Užice	8.7	0.2	6.9	2.8	2.8	2.8	14	14	14	23.6	16.5	22.2
Zaječar	10.5	1.2	8.8	3.0	3.0	3.0	14	14	14	25.3	17.5	23.9
Čačak	8.8	0.6	8.0	3.0	2.8	2.8	14	14	14	23.9	17.0	23.1
Kruševac	10.2	1.0	8.5	2.9	2.9	2.9	14	14	14	25.0	17.4	23.6
Nova Varoš	9.0	0.3	6.9	2.7	2.7	2.7	14	14	14	23.8	16.5	22.1
Niš	10.3	1.0	8.5	2.9	2.9	2.9	14	14	14	25.1	17.4	23.7
Kuršumlija	9.6	0.8	7.9	2.9	2.9	2.9	14	14	14	24.5	17.2	23.1
Novi Pazar	8.9	0.5	7.3	2.8	2.8	2.8	14	14	14	23.8	16.9	22.5
Pirot	10.0	1.0	8.4	3.0	3.0	3.0	14	14	14	25.0	17.4	23.6
Leskovac	10.2	1.0	8.5	3.0	3.0	3.0	14	14	14	25.0	17.4	23.6
Kosovska Mitrovica	9.4	0.8	7.8	2.8	2.8	2.8	14	14	14	24.3	17.1	22.9
Vranje	9.1	0.2	7.5	2.9	2.9	2.9	14	14	14	24.0	16.7	22.7
Đakovica	9.5	0.4	7.9	2.7	2.7	2.7	14	14	14	24.3	16.7	22.9
Prizren	9.7	−0.4	8.0	2.7	2.7	2.7	14	14	14	24.4	16.6	23.0

Irrespectable of the type of PV solar plants, PVGIS program has shown that most electrical energy in Serbia can be generated by PV solar plants with CdTe solar cells.

Acknowledgement

This paper was done with the financial support of the projects TR 33009 and OI 176008 approved by the Ministry of Education and Science of the Republic of Serbia.

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